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TWO APPROACHES TO CATEGORY REPRESENTATION IN AURAL CLASSIFICATION

James A. Ballas, and James H. Howard, Jr.

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The classification model proposed by Howard, Ballas and Burgy (1978) assumes that each category in a classification task is represented by an abstract prototype. Neumann (1977) argues that the evidence for prototype representations can be explained by the indeterminancy of exemplar attributes. A test of these two models would require that attribute indeterminancy be measured. In a classification task, attribute indeterminancy can lead to overlapping category boundaries. In turn, this results in confusions, which can then be a measure of indeterminancy. An

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aural classification experiment was conducted where listeners classified sixteen amplitude-modulated noise patterns into one of four, four-examplar categories. Results of a post training recognition test indicated that an unexperienced prototype was rated as familiar, but this effect was reduced with increased practice with the category examplars. Neither the prototype nor Neumann's model was supported unequivocally. Classification results did demonstrate that the classification model is applicable to four examplar categories defined in two dimensions.

One of the central issues in research on classification is whether categories are represented in memory by a list of category attributes or by a prototypical member. The former representation has been traditionally used in concept formation studies (Bourne & Restle, 1959). However, Posner (1969) has argued that the prototype representation may be more appropriate. In this case, the category is represented by an average of the attributes. New items are compared to the prototype of the category rather than being compared against a list of the attributes for each member in the category. Classification then involves computing a similarity measure between the test item and the prototype rather than counting the number of matching attributes between the test item and each known member.

The classification model developed by Howard, Ballas and Burgy (1978) uses prototypes to represent categories and computes similarity on the basis of the psychological distance between the prototype and the test item. The distance is expressed as a probability that the item belongs to the category and is based on fitting a Gaussian probability distribution to confusion matrix data. Each of these distributions are centered on the prototype for the category in a perceptual space. This assumption has two alternative implications. The first is a psychological implication and means that the prototype is the memorial representation of the category. The second is a statictical implication and means that the prototype is a convenient description of the location of a probability distribution for a category in a psychological space. This implication need not

mean that the prototype resides in memory. It is based on the assumption that the assignment of stimuli to categories is probabilistic. If this is so, then the category can be represented by a probability distribution in some psychological space. The centroid of this distribution is a statistical prototype, but need not be a cognitive prototype.

Research supporting the prototype representation has found that listeners do as well classifying prototypes on which they have not been trained as they do classifying examples on which they were trained. Neumann (1977) has argued that these results can be explained by the indeterminancy of exemplar representations. He says that an attribute is not represented on a dimension as a single point, but as an interval. The intervals representing attributes of several exemplars of a category could overlap and increase the frequency or strength of an attribute value that was not actually experienced.

Categories are represented in his model by a multidimensional mode of the attributes of the exemplars. Thus the attributes that occur most often in the exemplars will represent the category. By extending the representation of an attribute from a point value to encompass an interval, he allows unexperienced values to be representative of the category. In fact, if a midvalue between two exemplars is not experienced but lies within the interval of each exemplar, it will build up greater representation frequency than either experienced value, and account for the data which support the prototype

representation. Whereas the prototype is based on a multidimensional mean of the exemplars, category representation in Neumann's model is based on a count of the attributes.

An experiment was conducted to test Neumann's model against the prototype model. In order to make a clear test between the two, the experiment was designed so that the amount of overlap between attributes could be inferred. The stimuli were amplitude modulated noise sounds similar to those used by Howard et al (1978). However, the values of the stimuli were chosen so that subjectively, intracategory differences were identical to intercategory differences. In this case, the confusions in a classification task provide a measure of intercategory overlap. Since the intracategory differences would be the same, the confusions also provide a measure of attribute overlap within a category. In order to eliminate Neumann's indeterminancy as an explanation, the differences between stimuli were increased as much as possible. This sould result in very good classification and little overlap between attributes. If the prototype is still recognized under these conditions, it would not be due to attribute indeterminancy. Two-dimensional categories were used with four exemplars per catagory. A physical representation of the stimuli and the categories is shown in Figure 1.

Insert Figure 1 Here

Note that if no confusions between any of the categories are made, then there should be no overlapping representations of

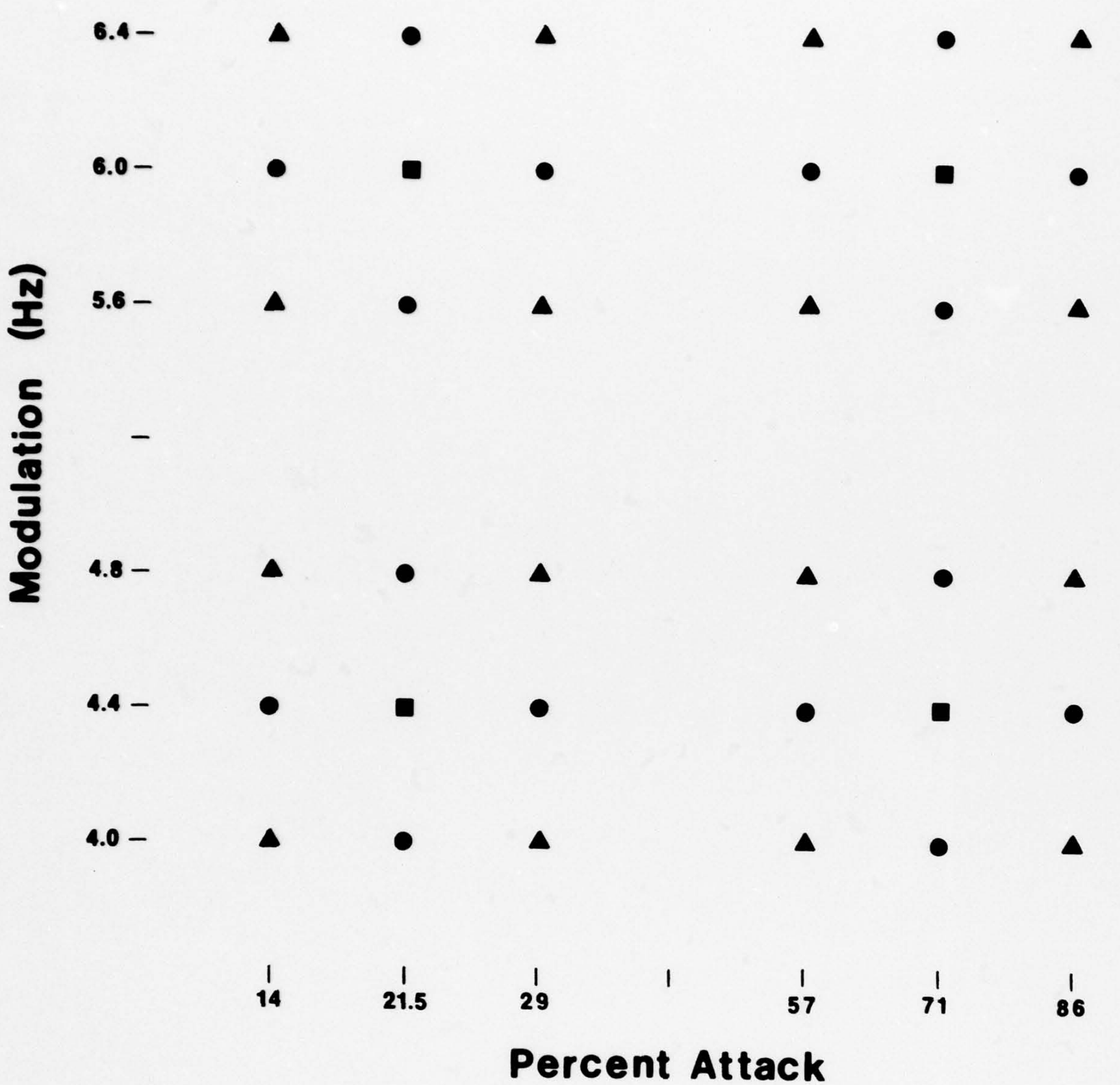

Figure 1. Representation of the training sounds (triangles), new test sounds (circles), category prototypes (squares) in the two-dimensional physical space.

attributes within a category. According to Neumann, there should be no unexperienced attributes that represent a category if there is no overlap. In contrast, according to the prototype assumption, the category should be best represented by the centroid of the four exemplars in each category.

This study also was designed to test the classification model developed by Howard et al (1978) with categories composed of four exemplars. Previous research always used two exemplar categories. The prototype assumption is particularly critical with the four exemplar categories used in this experiment since the centroid does not share any attribute with the exemplars on the two relevant dimensions.

Method

Participants. Six undergraduate students were solicited by advertisements to be paid listeners in this experiment. This group included four females and two males, and none reported any hearing deficiencies.

Apparatus. All experimental events were controlled by a laboratory digital computer. Modulation waveforms were synthesized by the computer and output on a 12-bit digital-to-analog converter at a 5 kHz sampling rate. This signal was applied to the input of a laboratory-constructed transconductance operational amplifier circuit (RCA CA3084). The output gain of the operational amplifier was directly proportional to the amplitude of the modulation signal. These amplitude-modulated signals were delivered to listeners over

matched Telephonics TDH-49 headphones with MX-41/AR cushions.

Stimuli. A set of 36 amplitude modulated noise signals was generated by combining six levels of amplitude modulation (4, 4.4, 4.8, 5.6, 6.0, and 6.4 Hz) and six levels of attack (14%, 21.5%, 29%, 57%, 71%, and 86% of the period). The former dimension defines the Tempo of the sound and the latter dimension defines the Quality of the sound. The values on the Tempo dimension were identical to those used in previous studies. The values on the attack dimension define a greater range than what has been used previously. This was done since previous research indicated that Quality had been underestimated. Expanding the range would make the Quality differences more discriminable. A subset of these stimuli were used as the training set. These 16 stimuli were partitioned into four categories as shown in Figure 1. Each category was given a CVC name for training. A second subset consisted of 16 stimuli which shared one but not both of the attributes of nearby exemplars, and 4 stimuli representing the prototypes of the categories and sharing none of the specific attributes of the exemplars. This subset together with the training set was used during the test phase.

The noise carrier was 20 Hz - 20 kHz white noise. The modulated signals have sawtooth waveform with the percentage of attacks above. All signals were presented at about 65 dB SPL.

Procedure. The listeners were tested individually in a sound attenuated booth. The experiment consisted of two parts, a training and a testing phase. For the training phase, the

subjects were told that their task was to learn to classify 16 sounds into four categories, four sounds per category. No specific instructions were given about how Tempo and Quality were to be used. Each trial began with a visual warning followed by either a 2.5 or 3.0 sec presentation of one of the sounds. The presentation length was randomly changed between these two values so that the listeners could not simply count the number of modulation pulses to determine the Tempo. After the sound ended, the listener pressed one of four keys (labeled with CVC category names of equal association value) to indicate the category for the sound. Feedback was provided after each trial.

For the testing phase, listeners were told their task was to listen carefully to a set of sounds and indicate whether they had heard the sounds in the first phase. After hearing each sound, they pressed one of five buttons to indicate one of the following answers:

1 = I am sure I did not hear it.

2 = I do not think I heard it.

3 = I do not know whether I heard it.

4 = I think I heard it.

5 = I am sure I heard it.

The listeners were told that about half of the sounds used in the testing phase were not used during the training phase.

Each block consisted of one training and one testing phase. In the training phase, each listener received 16 repetitions on each sound for a total of 192 trials. In the testing phase, each

listener received 2 repetitions on each of the 36 sounds for a total of 72 trials. All trials were presented in random order. A block took approximately 45 minutes to complete. Each subject completed four blocks, each block on a separate day.

Results and Discussion

Overall Performance. The performance of the six listeners ranged from 47% to 67% on the first block and from 63% to 93% on the fourth block as shown in Figure 2.

Insert Figure 2 Here

Performance increments were not as steep as in previous work with similar stimuli due to the high level of initial performance. Four of the six subjcts achieved better than 85% performance, or fewer than 30 errors in 192 trials. If all these errors were confusions at category boundaries, this would be about 3 out of 15 possible confusions at each boundary point. In a general sense, this error rate defines the amount of overlap between adjacent stimulus values. It is this overlap that Neumann claims produces the prototype effect. In terms of normal distributions overlapping at a boundary, these confusions represent about 16% of each distribution on the incorrect side of the boundary. It is reasonable to assume that this also describes the spread of the attribute within the category. If the ordinate is taken as the measure of attribute frequency, then the frequency of unexperienced attributes would be greater than the frequency of experienced attributes. Thus the stimuli were not sufficiently

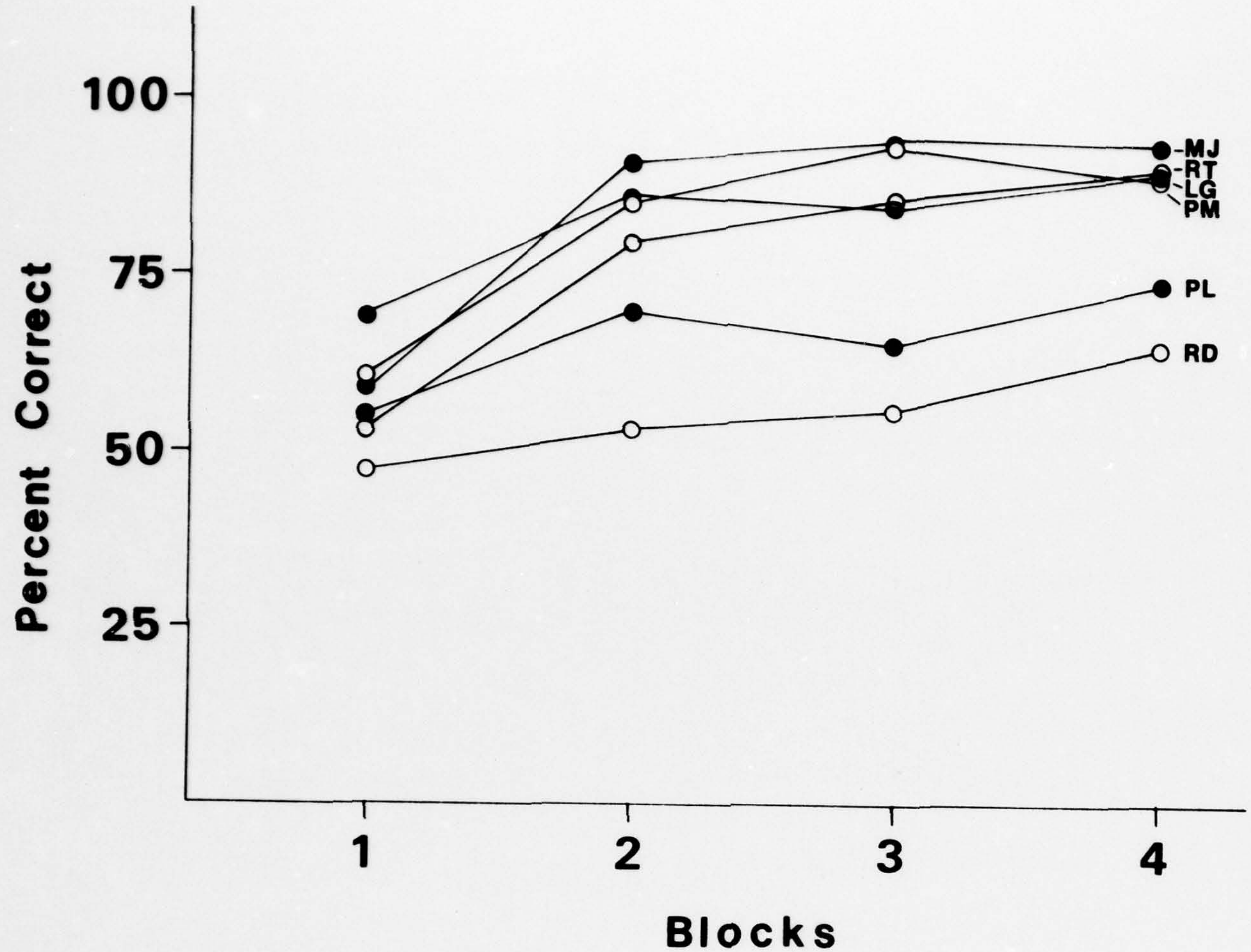

Figure 2. Performance of the six listeners by block.

distinct to exclude the possibility of attribute overlap.

Test Phase Results. The reponses in the test phase were used as a five point interval scale and were summed and averaged within each block by the type of stimuli--old, new or prototype. These averages were analyzed with ANOVA using a stimuli (3) by blocks (4) repeated measures design. No significant effects were found (see Table 1).

Insert Table 1 Here

However, the blocks effect was nearly significant ($F(3,15) = 3.29$, $p = .07$) and the blocks by stimulus effect was large. The nature of these effects is shown in Figure 3.

Insert Figure 3 Here

The general decrease in recognition scores from block one to four was accentuated for the prototype scores. Because of the large variance in the scores, these effects failed to reach significance. Therefore, a Freedman nonparametric rank test (Siegel, 1956) was used to test whether the ranking of the three stimuli was different on blocks one and four. There was a significant difference for block one (X (2) = 6.33, $p = .05$) but not for block four (X (2) = .33). In block one, five of the listeners had the highest recognition score and the sixth had the second highest score for the prototype stimuli. These ranks indicate that the prototype was better recognized on the first

Table 1

Analysis of Variance on Average Recognition Scores

Source	df	MS	F
Between subjects (S)	5	15087.6	
Within subjects			
Stimuli (St)	2	931.1	.59
Blocks (B)	3	8438.9	2.87
St x B	6	1921.2	1.83
St x S	10	1578.3	
B x S	15	2939.6	
St x B x S	30	1051.6	

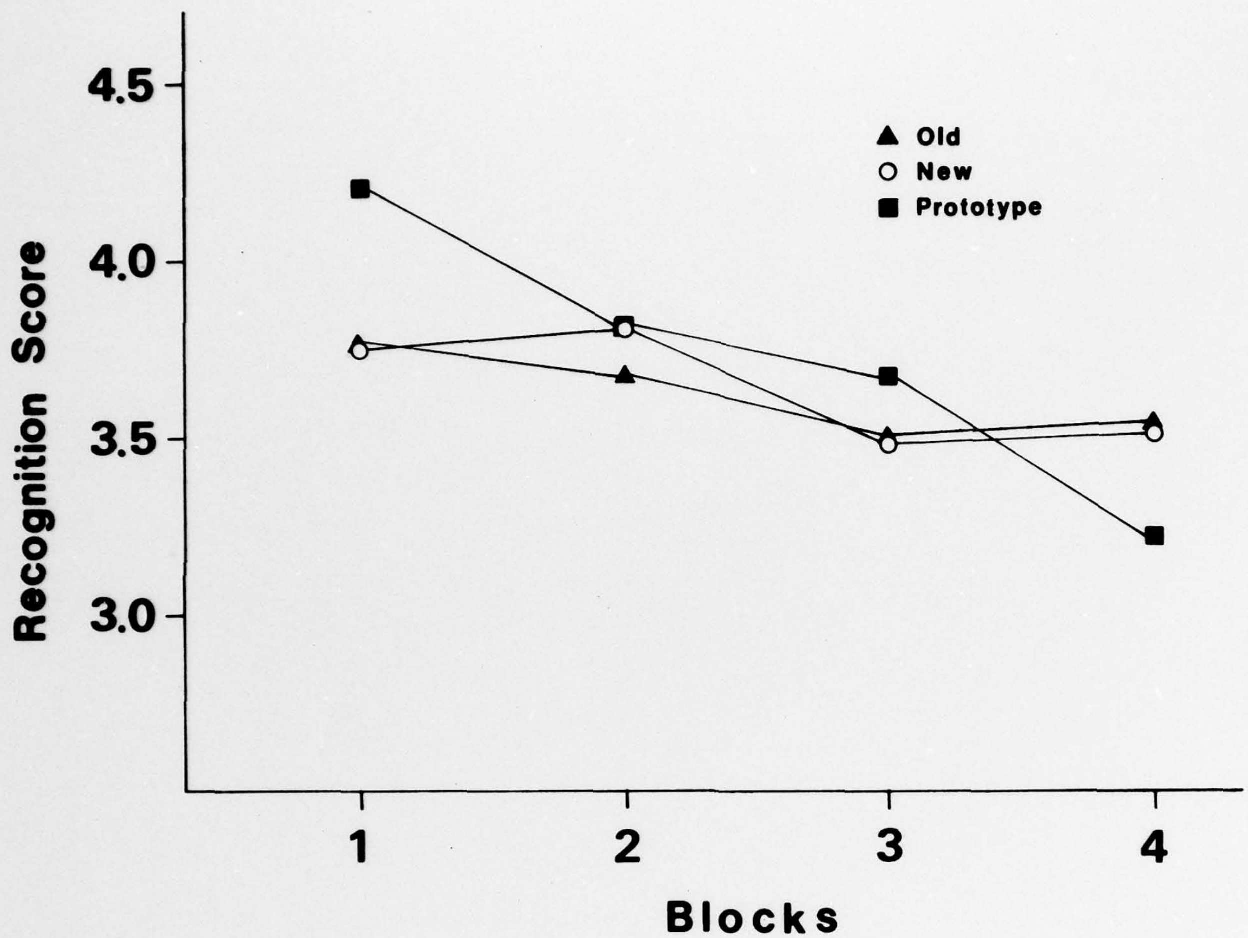

Figure 3. Average recognition scores by type of sound and block.

block, but with experience, was no better recognized than the others by the fourth block. This means that learning affects the reliance on prototype knowledge. These results are similar to those by Robbins, Barresi, Compton, Furst, Russo and Smith (1978) who found that exemplar specific knowledge is used when testing occurs without delay, but that abstract category knowledge is used when testing is delayed after training.

In terms of deciding between the prototype and Neumann's attribute frequency model, the stimuli were not sufficiently distinct for a clear test. Even on the fourth block there was enough overlap of attributes to provide a basis for prototype recognition according to Neumann's indeterminancy explanation. Altogether, these results *provide evidence neither for nor* against Neumann's model. They would appear to weaken the prototype assumption since the recognition scores decrease with practice. However, using a recognition question in the testing phase does not assess the possibility that the prototype may be the best representation of the category. The prototype might be perceived as not having been presented during training even though it best represents the category. A classification task may be more appropriate during the testing phase especially if this task requires the listeners to rate the representativeness of the stimuli for a particular category.

<u>Theoretical analysis</u>. In order to test the classification model with four exemplar categories, theoretical confusion matrices were generated to fit the obtained matrices using a

gradient algorithm (subroutine ZXMIN in the IMSL mathematical subroutine library). The theoretical matrices are based on a standard deviation parameter for each dimension and it is these two parameters that are estimated by the algorithm. To assess the fit, correlations between the theoretical and obtained matrices were calculated. Across all listeners and blocks, the correlation was +.96, indicating that 92% of the variance was explained by the classification model. The correlations for the six listeners ranged from +.85 to +.98 and across all blocks and listeners from +.82 to +.995. These results show that the model is applicable to four exemplar categories and accurately estimates the type of confusions that are made.

The attentional effort parameters estimated by the classification model can be used to determine whether the listeners were using an optimal strategy. With these stimuli and the categories, an optimal processor would place equal emphasis on both relevant dimensions and would allocate attentional effort equally. Estimates of the attentional effort parameters were generated and are shown in Figure 4.

Insert Figure 4 Here

These results show that none of the listeners operated consistently as optimal processors. All but one placed greater emphasis on the Quality dimension. This was a reversal of previous research which indicated that Quality was consistently under emphasized. The discrimination on the Quality dimension

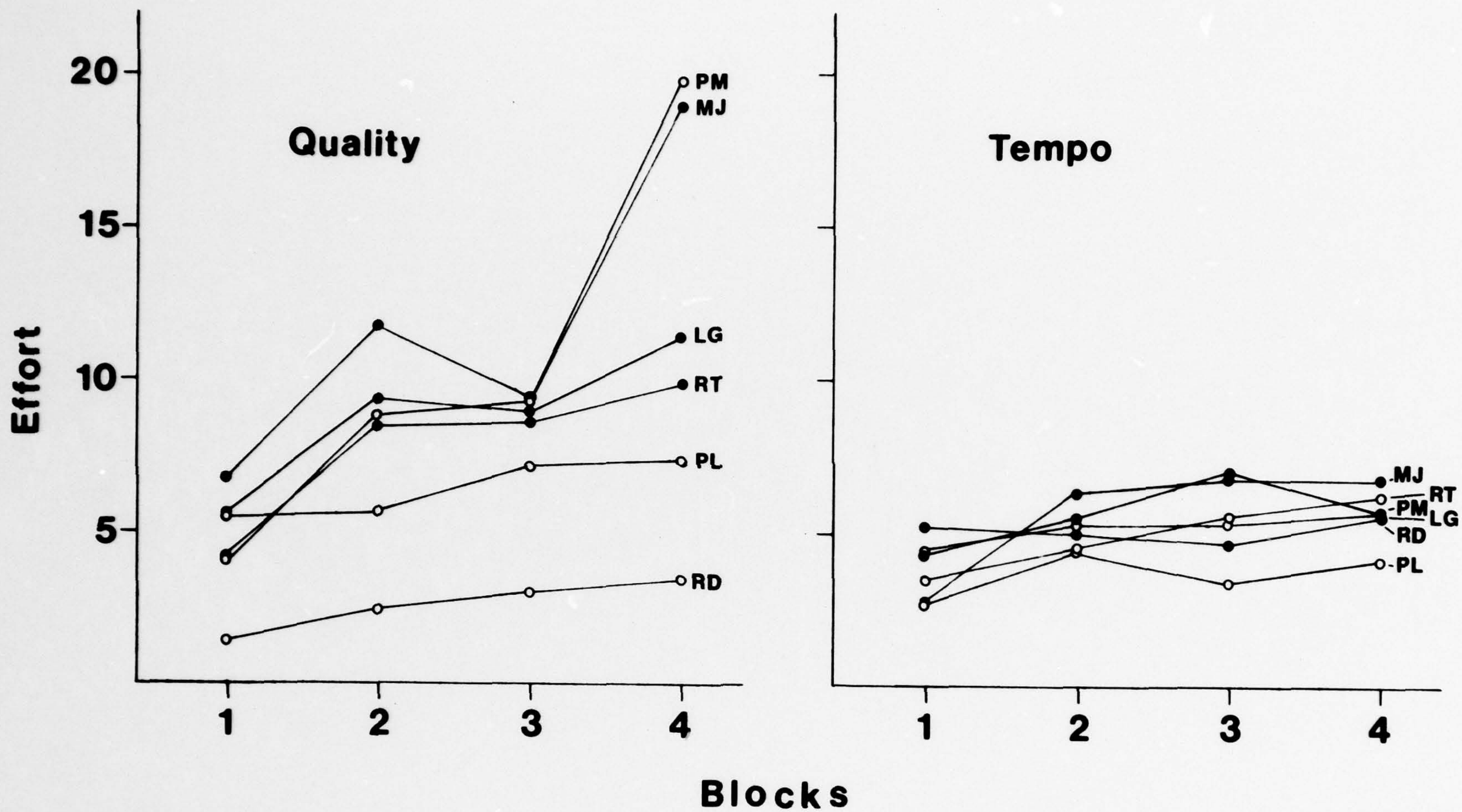

Figure 4. Estimated attentional effort parameters by block and listener.

was enhanced in this experiment because of the previous results. However, the enhancement was apparently more than was necessary to have the listeners equally emphasize the two dimensions. The values chosen for Quality may have enhanced a bimodality along this dimension. Post test debriefing indicated that the listeners were perceiving the four Quality values in terms of two levels. However, the Tempo dimension was still perceived as changing on four levels, making a bimodal discrimination more difficult. In order to fully explain these results, a discrimination-classification experiment should be conducted to determine the psychophysical function for both dimensions and whether there is any occurrence of categorical perception (Macmillan, Kaplan & Creelman, 1977).

Acknowledgements

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